System Dynamics Simulation in Support of Obesity Prevention Decision-Making

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For Institute of Medicine Committee on an Evidence Framework for Obesity Prevention Decision-Making

Irvine, California

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Agenda

- System Dynamics Background
- Obesity Life-Course Model (2005-2006, CDC)
- Cardiovascular Risk Model (2007-2010, CDC & NIH)
Re-Directing the Course of Change

Questions Addressed by System Dynamics Modeling

Where?

Prevalence of Obese Adults, United States

Historical Data: NHANES


Why?

Regression Model Assumes
• Linear growth (by age, sex)

Who?

How?

Simulation Experiments

Regression Forecast
Types of Models for Policy Planning & Evaluation

- **Time Series Models**
  - Describe trends
- **Multivariate Statistical Models**
  - Identify historical trend drivers and correlates
- **Dynamic Simulation Models**
  - Anticipate new trends, learn about policy consequences, and set justifiable goals

Events
- Increasing:
  - Depth of causal theory
  - Robustness for longer-term projection
  - Value for developing policy insights
  - Degrees of uncertainty
  - Leverage for change
System Dynamics
Simulating Dynamic Complexity

Origins
- Jay Forrester, MIT, *Industrial Dynamics*, 1961 ("One of the seminal books of the last 20 years."-- NY Times)
- Public policy applications starting late 1960s
- Population health applications starting mid-1970s

Good at Capturing
- Differences between short- and long-term consequences of an action
- Time delays (e.g., incubation period, time to detect, time to respond)
- Accumulations (e.g., prevalences, resources, attitudes)
- Behavioral feedback (reactions by various actors)
- Nonlinear causal relationships (e.g., threshold effects, saturation effects)
- Differences or inconsistencies in goals/values among stakeholders

System Dynamics Health Applications
1970s to the Present

• Disease epidemiology
  – Cardiovascular, diabetes, obesity, HIV/AIDS, cervical cancer, chlamydia, dengue fever, drug-resistant infections

• Substance abuse epidemiology
  – Heroin, cocaine, tobacco

• Health care patient flows
  – Acute care, long-term care

• Health care capacity and delivery
  – Managed care, dental care, mental health care, disaster preparedness, community health programs

• Health system economics
  – Interactions of providers, payers, patients, and investors

An (Inter) Active Form of Policy Planning/Evaluation

System Dynamics is a methodology to…

• **Map** the salient forces that contribute to a persistent problem;

• Convert the map into a **computer simulation model**, integrating the best information and insight available;

• Compare results from **simulated “What If…” experiments** to identify intervention policies that might plausibly alleviate the problem;

• Conduct **sensitivity analyses** to assess areas of uncertainty in the model and guide future research;

• Convene **diverse stakeholders** to participate in model-supported “Action Labs,” which allow participants to **discover for themselves** the likely consequences of alternative policy scenarios.
An Ecological Framework for Organizing Influences on Overweight and Obesity

- Social Norms and Values
  - Home and Family
  - School
  - Community
  - Work Site
  - Healthcare
- Sectors of Influence
- Behavioral Settings
- Individual Factors
- Food and Beverage Intake
  - Energy Intake
- Physical Activity
  - Energy Expenditure
- Energy Balance

Prevention of Overweight and Obesity Among Children, Adolescents, and Adults

The Obesity “System”: A Broad Causal Map

LEGEND: Blue arrows indicate same direction links; Green arrows indicate opposite direction links; R loops indicate reinforcing processes; B loops indicate balancing processes.

NOTE: All parameters vary by social position (e.g., age, sex, race/ethnicity, income, geography).

Date: 5/8/05
Broad Dynamics of the Obesity Challenge

Prevalence of Vulnerability, Risk, or Disease

Engines of Growth
R1 Spiral of poor health and habits
R2 Parents and peer transmission
R3 Media mirrors
R4 Options shape habits shape options
R5 Society shapes options shape society

Potential Threats

Drivers of Growth

Responses to Growth
B1 Self-improvement
B2 Medical response
B3 Improving preventive healthcare
B4 Creating better messages
B5 Creating better options in beh. settings
B6 Creating better conditions in wider environ
B7 Addressing related health conditions

Health Protection Efforts

Resources, Resistance, Benefits & Supports
R6 Disease care costs squeeze prevention
B8 Up-front costs undercut protection efforts
B9 Defending the status quo
B10 Potential savings build support
R7 Broader benefits build support
The Closed-Loop View Leads Us To Question…

• How can we weaken the engines of growth loops (i.e. social and economic reinforcements)?

• What incentives can reward parents, school administrators, employers, and other decision-makers for expanding healthy diet and activity options?

• Are there resources for health protection that do not compete with disease care?

• How can industries be motivated to change the status quo rather than defend it?

• How can benefits beyond weight reduction be used to stimulate investments in expanding healthier options?
Mapping and Modeling

Two systems thinking tools:

- Causal loop diagramming (mapping)
- Mathematical simulation (modeling)

Causal diagrams provide a ‘macroscopic’ view that goes beyond ‘laundry list’ thinking by introducing circular causality.

Maps reveal possibilities, but are not testable. They have little explanatory power and cannot weigh the relative importance of factors.

A useful evidence-based systems framework includes both maps and models.

“Without modeling, we might think we are learning to think holistically when we are actually learning to jump to conclusions.”

– John Sterman

Simulation and “Double-Loop Learning”

- **Real World**
  - Unknown structure
  - Dynamic complexity
  - Time delays
  - Impossible experiments

- **Virtual World**
  - Known structure
  - Controlled experiments
  - Enhanced learning

- **Decisions**
  - Implementation
  - Game playing
  - Inconsistency
  - Short term
  - Inability to infer dynamics from mental models

- **Information Feedback**
  - Selected
  - Missing
  - Delayed
  - Biased
  - Ambiguous
  - Misperceptions
  - Unscientific
  - Biases
  - Defensiveness

- **Strategy, Structure, Decision Rules**
  - Implementation
  - Game playing
  - Inconsistency
  - Short term
  - Inability to infer dynamics from mental models

**What is a System? What are Dynamics?**

**System (Structure) = Stocks + Flows + Feedback Loops +...**

- **Stocks** are accumulations of **flows** (of population, resources, changing goals, perceptions, etc.)
- **Feedback loops** link accumulations back to decisions that alter the flows: only 2 types (goal-seeking, self-reinforcing)
- **Delays** complicate things further
- As do **non-linearities** (need for critical mass, saturation effects)

**Dynamics = Behavior over time**

- **Patterns** in time series data (growth, fluctuation, etc.)
- Visible **relationships** of two or more variables (move together, move opposite, lead-lag, etc.)
The Modeling Process is Iterative…

Adapted from Saeed 1992

Empirical...and...Critical


Practical Options in Causal Modeling

- Simplistic: Too hard to verify, modify, and understand
- Expansive: Impractical
- Focused

Scope (Breadth)
- Low
- High

Detail (Disaggregation)
- Low
- High
Model Structure and Level of Detail
Depends on the Intended Uses and Audiences

• Set Better Goals (Planners & Evaluators)
  – Identify what is likely and what is possible
  – Estimate intervention impact time profiles
  – Evaluate resource needs for meeting goals

• Support Better Action (Policymakers)
  – Explore ways of combining policies for better results
  – Evaluate cost-effectiveness over extended time periods
  – Increase policymakers’ motivation to act differently

• Develop Better Theory and Estimates (Researchers)
  – Integrate and reconcile diverse data sources
  – Identify causal mechanisms driving system behavior
  – Improve estimates of hard-to-measure or “hidden” variables
  – Identify key uncertainties to address in intervention studies

Tests for Building Confidence in Simulation Models

<table>
<thead>
<tr>
<th></th>
<th>Focusing on STRUCTURE</th>
<th>Focusing on BEHAVIOR</th>
</tr>
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<tbody>
<tr>
<td>ROBUSTNESS</td>
<td>• Dimensional consistency</td>
<td>• Parameter (in)sensitivity</td>
</tr>
<tr>
<td></td>
<td>• Extreme conditions</td>
<td>• Structure (in)sensitivity</td>
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<td></td>
<td>• Boundary adequacy</td>
<td></td>
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<tr>
<td>REALISM</td>
<td>• Face validity</td>
<td>• Replication of behavior</td>
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<tr>
<td></td>
<td>• Parameter values</td>
<td>• Surprise behavior</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Statistical tests</td>
</tr>
<tr>
<td>UTILITY</td>
<td>• Appropriateness for audience and purposes</td>
<td>• Counterintuitive behavior</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Generation of insights</td>
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The Future of Systems Simulation

• More ambitious models, addressing big strategic questions
• Supporting macro-models with more empirical data, but also with the results of focused (operational, mechanistic) micro-models
• Improved use of expert judgment; e.g., Delphi method
• More use of software tools for automated model calibration, sensitivity testing, and documentation
• Better public outreach through logical, balanced presentation that provides clear path from evidence to insight

“There seems to be a common attitude that the major difficulty is shortage of information and data. Once data are collected, people feel confident in interpreting the implications. I differ on both of these attitudes. The problem is not shortage of data but rather our inability to perceive the consequences of the information we already possess.”

– Jay Forrester

Obesity Life-Course Model
(with CDC, 2005-2006)

• Initially considered obesity dynamics broadly

• Narrowed to address a strategic policy question:
  – How do changes in caloric balance affect the future BMI distribution across the life-course?
  – What does that imply for intervention strategy?


Focusing on Life-Course Dynamics

• Explore likely consequences of possible interventions affecting caloric balance (intake less expenditure)
  – How much impact on obesity prevalence?
  – How long will it take to see?
  – Should we target particular subpopulations?
    (age, sex, weight category; lack data for race, ethnicity)

• Consider interventions broadly but leave details (composition, coverage, efficacy, cost) outside model boundary for now
  – Available data inadequate
  – Would require a separate research effort to estimate these details
  – Not addressing feedback loops of reinforcement and resistance
  – Not addressing cost-effectiveness
Population Weight-Change Dynamics
From Caloric Balance to Obesity Prevalence

Dynamic Population Weight Framework

Caloric Balance → Flow-rates between BMI categories

Birth → Immigration → Yearly aging → Population by Age (0-99) and Sex

Not Overweight → Moderately Overweight → Moderately Obese → Severely Obese

Overweight and obesity prevalence → Death

Detail of Aging and BMI Change Processes

Two Classes of Interventions
Population-based and Individual services

Dynamic Population Weight Framework

Changes in the Physical and Social Environment
Trends and Planned Interventions
Weight Loss/Maintenance Services for Individuals

Caloric Balance
Flow-rates between BMI categories

Not Overweight
Moderately Overweight
Moderately Obese
Severely Obese

Population by Age (0-99) and Sex

Birth
Immigration
Yearly aging
Death

Overweight and obesity prevalence

Possible Extensions

Indicates possible extensions to the existing model
Reproducing Historical Data
One of 20 \{sex, age\} Subgroups: Females age 55-64

(a) Overweight fraction
(b) Obese fraction
(c) Severely obese fraction

Note: S-shaped curves, with inflection in the 1990s
Alternative Futures for Teenage Obesity
Alternative Futures for Adult Obesity

Obese fraction of Adults (Ages 20-74)

Fraction of popn 20-74

Base
SchoolYouth
AllYouth
School+Parents
AllAdults
AllAges
AllAges+WtLoss


CDC
Results of Simulated Interventions

Environmental change approach
(reduce caloric balances to their 1970 values by 2015 for selected age ranges)

• Youth interventions have only small impact on overall adult obesity *(assuming adult habits determined by adult environments—not by childhood)*

• Slow decline in overall adult obesity, even when program covers all ages

Targeted weight loss approach
(obese lose 4 lbs per year, program terminated 2020)

• Such a program could accelerate progress and “buy time” for environmental change *(but first, need to find a cost-effective program with lasting benefits—minimal relapse)*

Need to assure caloric balance throughout all ages, particularly adulthood.

Contrast today’s narrow national focus on school-age youth.

Also need research on extent to which adult habits are determined by childhood.

Cardiovascular Disease Intervention Strategy
(with CDC and NIH, 2007-10)

- What are the key **pathways of CV risk**, and how do these affect **health outcomes and costs**?
- How might **interventions** affect the risk factors and outcomes in the short- and long-term?
- How might policy efforts be better **balanced** given limited resources?

The CDC has partnered on this project with the Austin (Travis County), Texas, Dept. of Health and Human Services. The model is calibrated to represent the overall US, but is informed by the experience and local data of the Austin team.


Homer J, Milstein B, Wile K, Trogdon J, Huang P, Labarthe D, Orenstein D. Simulating and evaluating local interventions to improve cardiovascular health. In submission to *Preventing Chronic Disease*. 
Risk Factors for CVD

Data sources: NHANES, NHIS, MEPS, AHA/NIH reports, Census, Vital Statistics, Framingham risk calculators, literature on risk factors and costs
Tobacco and Air Quality Interventions

Data sources: NHANES, NHIS, MEPS, AHA/NIH reports, Census, Vital Statistics, Framingham risk calculators, literature on risk factors and costs
Health Care Interventions

- Quality of primary care provision
- Access to and marketing of primary care
- Anti-smoking social marketing
- Tobacco taxes and sales/marketing regulations
- Access to and marketing of smoking quit products and services
- Smoking bans at work and public places
- Particulate air pollution
- Downward trend in CV event fatality
- First-time CV events and deaths

Smoking

- Diagnosis and control
- Secondhand smoke

Obesity

- Healthiness of diet
- Extent of physical activity

Chronic Disorders

- High BP
- High cholesterol
- Diabetes

Data sources: NHANES, NHIS, MEPS, AHA/NIH reports, Census, Vital Statistics, Framingham risk calculators, literature on risk factors and costs
Interventions Affecting Stress

Data sources: NHANES, NHIS, MEPS, AHA/NIH reports, Census, Vital Statistics, Framingham risk calculators, literature on risk factors and costs
Healthy Diet Interventions

Data sources: NHANES, NHIS, MEPS, AHA/NIH reports, Census, Vital Statistics, Framingham risk calculators, literature on risk factors and costs
Physical Activity & Weight Loss Interventions

Data sources: NHANES, NHIS, MEPS, AHA/NIH reports, Census, Vital Statistics, Framingham risk calculators, literature on risk factors and costs
Adding Up the Costs

Data sources: NHANES, NHIS, MEPS, AHA/NIH reports, Census, Vital Statistics, Framingham risk calculators, literature on risk factors and costs
Scenario #1: Reduce Childhood Obesity

Scenario #2: Improve Adult Diet & Activity

Scenario #3: Expand Weight-loss Services for Obese Adults

Graphs of assumptions

Obese Fraction of Age 18

Poor Diet Fraction

Inadequate Physical Activity Fraction

Use of Weight Loss Services (by non-CVD Obese)

Based on output from the obesity life-course model

Maximum plausible interventions for access and social marketing

Maximum plausible interventions for access and service marketing
Obesity prevalence in adults (18+)
(all subgroups combined)

As in the life-course model, lower childhood obesity accounts for only 12% of the adult prevalence reduction projected in the full-population approach of "Teen_DietPA".

-3.5%
-30.5%
-37.2%
Further Consequences

PERCENTAGE REDUCTION FROM BASE CASE VALUE IN 2040, BY SCENARIO

<table>
<thead>
<tr>
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<th>Teen obesity down 70%</th>
<th>plus better adult diet and physical activity</th>
<th>plus more use of weight loss services</th>
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<tbody>
<tr>
<td>Obese fraction of adults</td>
<td>3.5%</td>
<td>30.5%</td>
<td>37.2%</td>
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<tr>
<td>(base2040=.339)</td>
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<tr>
<td>High blood pressure fraction</td>
<td>0.4%</td>
<td>8.9%</td>
<td>10.4%</td>
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<tr>
<td>of adults (base2040=.449)</td>
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<tr>
<td>High cholesterol fraction</td>
<td>0.3%</td>
<td>8.9%</td>
<td>9.6%</td>
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<tr>
<td>of adults (base2040=.435)</td>
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<tr>
<td>Diabetic fraction of adults</td>
<td>0.4%</td>
<td>16.8%</td>
<td>19.5%</td>
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<tr>
<td>(base2040=.163)</td>
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<tr>
<td>Heart attacks</td>
<td>0.1%</td>
<td>3.2%</td>
<td>3.7%</td>
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<td>(base2040=3.077M/yr.)</td>
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<tr>
<td>Strokes</td>
<td>0.1%</td>
<td>4.1%</td>
<td>4.9%</td>
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<tr>
<td>(base2040=1.447M/yr.)</td>
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<tr>
<td>Combined CV events</td>
<td>0.1%</td>
<td>3.3%</td>
<td>3.8%</td>
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<tr>
<td>(base2040=7.424M/yr.)</td>
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<tr>
<td>Deaths from CV events</td>
<td>0.1%</td>
<td>5.5%</td>
<td>6.4%</td>
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<tr>
<td>(base2040=1.603M/yr.)</td>
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<tr>
<td>Other deaths from CV risk</td>
<td>0.2%</td>
<td>3.9%</td>
<td>4.5%</td>
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<tr>
<td>factors (base2040=1.217M/yr.)</td>
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<tr>
<td>Total consequence costs</td>
<td>0.1%</td>
<td>5.0%</td>
<td>5.4%</td>
</tr>
<tr>
<td>(base2040=1.418Tr/yr.)</td>
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The three policies combined, through 2040, could reduce cumulative deaths by 2.36M and cumulative consequence costs by $1.08Tr
Strategic Uses of Simulated Scenarios

- We plan to extend this model
  - Borderline conditions, ex-smokers
  - Downstream interventions and costs

- Investigate transferability of this model to other locales

- Tools allowing wider dissemination

- What do you need for this to be useful?

- Needs for other systemic analyses?

CDC
Simulations for Learning in Dynamic Systems

Multi-stakeholder Dialogue

Dynamic Hypothesis (Causal Structure)  Plausible Futures (Policy Experiments)